

INTEGRATED APPLICATION OF ADVANCED SURVEYING TECHNIQUES AND BIM FOR INSPECTION AND ASSET MANAGEMENT OF REINFORCED CONCRETE BRIDGES

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Abstract

The aim of the work reported herein was to explore the possibilities of integrating new ways of surveying into RC bridge inspection activities and evaluating the possibility of integrating data into a BIM model, as to allow quick overviews to be obtained after each inspection. Efforts were made in regard to modelling strategies, not only of the RC bridge elements, but also of 'damage' information that required special attention, as to allow non-graphic information to be easily retrievable. Special tools (add-ins to the BIM platform) were also developed in order to allow quick introduction of inspection data into the BIM model through Excel spreadsheets. The concepts/methods proposed were put to test in an extensive inspection to a bridge located in the north of Portugal. This work results from a collaboration of the University of Minho with Betar, a consulting office with more than 20 years of experience in Bridge inspection, which has authored a managing system for road infrastructure and actively applies it.

1. Introduction

Bridges and viaducts are very important and fundamental assets for road/railway infrastructure managers, who need to manage the information of each structure in an organized manner as to perform timely reactions and maintenance activities to ensure safety, adequate service levels and durability. Most countries in the world have national infrastructure strategies for inspection, with Portugal having issued their latest inspection manual in 2015 [1]. Several types of inspection are envisaged (as well as their timing), from the simplest routine ones, to the most complex, the special inspections that intend to gather extensive information on the entire asset or specific aspects of it. In spite of the well-structured activities in such manuals, they are still lacking explicit references to the

integration of the inspection information into Building Information Modelling (BIM) frameworks, particularly taking into account the opportunities brought about by new/emerging surveying inspecting techniques (e.g. laser scanning, GPR, thermography, 360 photography). This is not necessarily a ground-breaking activity in view of the extensive recent developments occurring in BIM at the '*facilities management*' discipline (BIM-FM) [2]. However, very little has been done in applied discussion of the challenges and opportunities brought about by BIM-FM in the particular scope of reinforced concrete bridges that incorporate a set of specificities. This was therefore the main aim of the present work, that focused in the application of BIM methodologies to the extensive survey/inspection of a reinforced concrete bridge located in the North of Portugal. The work carried out was closely monitored and supported by the company Betar, which has authored a widely-used system for infrastructure management in Portugal, named GOA (focus on bridges/viaducts) [3], but does not incorporate yet BIM-based technology in their inspection/management processes. It is also noted that the work reported herein is more extensively described in the MSc dissertation of the second author [4].

This paper is structured in two main parts in Sections 2 and 3: Section 2 presents the case study of the Saltadouro Bridge and a global overview of the survey/inspection actions that were carried out. Section 3, in turn discusses the processes and methods for producing the corresponding BIM model, with adequate incorporation of the inspection data. Final conclusions of the work are presented in Section 4.

2. Saltadouro Bridge: the case study

2.1 Description of Saltadouro Bridge

The Saltadouro Bridge is located in the North of Portugal, within the Natural Park of Gerês (Ruivães). It has been built in the 1950's, but the owner did not have any drawings or written records of the bridge design. The bridge, whose recent photo is shown in Figure 1, has two free spans of approximately 16.8m each, supported in a central column and two lateral abutments. The cross-section of the bridge is a double "T", with two longitudinal ribs supporting the top slab (all monolithically connected to each other). As seen in Figure 1, the water height is different in both spans of the bridge. For that reason, and taking into account the similar apparently similar state of both spans, the detailed inspection has been focused on the leftmost span according to Figure 1 (South side), which was made accessible by a specifically assembled scaffolding.



Figure 1: Overall view of Saltadouro Bridge (left side: North abutment; right side: South abutment).

2.2 Surveying and inspection actions

The surveying and inspection actions needed to be rather extensive in view of the total lack of information about the bridge. In terms of geometry, both manual processes (handheld laser

distance meter, measuring tape) and laser scanning techniques were applied for mutual validation. The laser scanning was carried out with a Leica ScanStation P40 with the following main features: survey of 1.000.000 points per second, range of 240m, 1.2mm precision (± 10 ppm) and integrated digital camera. The equipment was placed at 8 different measuring stations in order to cover the entire structure, as identified in Figure 2a. The resulting global point cloud has more than 170 million points. One view of such point cloud is shown in Figure 2b. From a structural point of view, it was interesting to note that the accuracy of the obtained point cloud, allowed to compare the actual shape of the bottom surface of the beams, to the hypothetical straight line that connects the supports, and therefore infer the deformation. As shown in Figure 2c, a deformation of 2.6cm could be assessed in regard to the fictitious straight line, and the noise level of the point cloud is compatible with the 1.2mm precision mentioned above. This level of accuracy brings laser scanning to a great degree of usefulness in accompanying the deformational behaviour of structures, indeed. It is also remarked that, as expected, all tape measurements have validated the measurements that could be made directly on the point cloud.

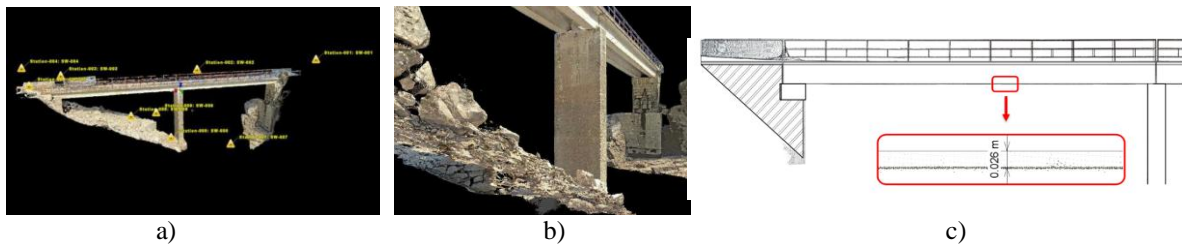


Figure 2: Laser scanning: a) location of stations; b) view of the point cloud; c) deformed shape in comparison to reference line

The inspection has also involved several inspection techniques that are briefly addressed here. Visual inspection (together with photographic record) allowed the traditional identification of biological colonization, corrosion, surface delamination and suchlike (e.g. corrosion and delamination in Figure 3a). Infrared thermography was also applied with a FLIR E50bx camera, that allowed recording several barely perceptible delamination processes to the naked eye (Figure 3b). In order to assess the rebar diameter, position and type, several minor destructive inspection activities were made, by opening cavities up to the reinforcement (here termed as inspection windows), and even gathering a few rebar samples for lab testing. Two steel rebar detectors were used together in order to get a global picture of all reinforcement distribution within the ribs and the deck: a Hilti PS200 detector and a Hilti PS1000 GPR based scanner. An example of the GPR imaging obtained can be seen in Figure 3c. Seven concrete cores (with ~ 10 cm diameter) were obtained from the bridge and tested in laboratory (Figure 4a). Schmidt hammer assessment of compressive strength was also assessed at 24 distinct locations. Cracks were marked with a felt pen and photographed, whereas a set of representative crack widths were measured with a handheld USB Microscope VEHO VMS-004D, that could accurately pinpoint widths to the hundredth of millimetre (Figure 4b).

The photographic record of the bridge was also taken through 360° photography at 7 locations with a Ricoh Theta camera. An example of a flattened spherical panorama can be seen in Figure 4c. These spherical photos can be of great utility due to the quickness in which they are obtained and the embedded richness of context.

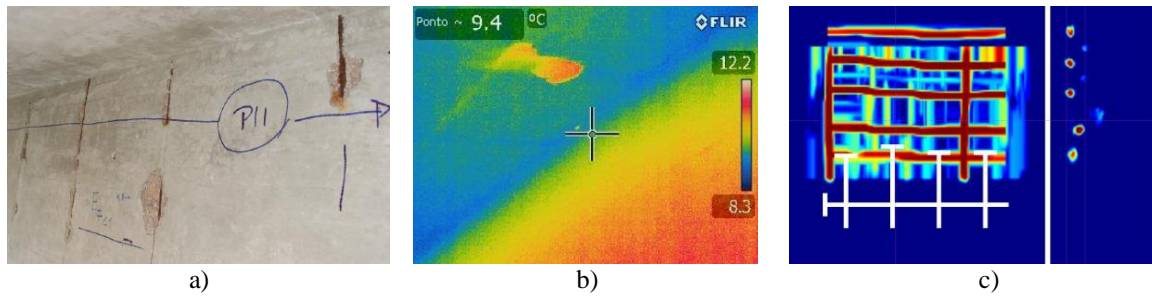


Figure 3: Inspection techniques: a) photography record of corrosion and delamination; b) infrared thermography image; c) GPR image obtained with a steel rebar detector



Figure 4: Inspection techniques: a) core extraction; b) crack width; c) 360° photography

3. BIM Model and data organization

The selected application for modelling was Autodesk REVIT, following a structural template that encompasses native object classes for such purpose. The point cloud was embedded as a reference in the BIM model and used to support the geometry definition throughout the entire process. In regard to the level of information/detail/development to be included in the model, it was decided to follow similar prescriptions to those provided by BIMFORUM/AIA for LOD400 [5], which means that reinforcement was explicitly modelled. Warping/deformations of the structure's geometry were not explicitly modelled, with the idealized undeformed geometry being considered sufficient for the intended use of the model. The final BIM model is shown in Figure 5a, with a specific comparison of the idealised geometry of the model with the point cloud being shown in half cross-section in Figure 5b. A view of the modelled reinforcement is shown in Figure 5c.

The modelling of inspection information can be made either explicitly, as shown for the cores exemplified in Figure 6a (which incorporate core objects that embed the relevant information of compressive strength, laboratory test sheets, carbonation depth, etc.) or in an implicit manner through 'patch' objects, such as the green patches shown in Figure 6b, which stand for the observed biological colonization. The mentioned patches are BIM objects themselves with relevant fields that characterize the information considered relevant (e.g. type of colonization, extent, link to photo, etc.) in such a way that it remains interoperable and exportable in a specific IFC 'property set'. The authors consider that, for the sake of BIM-FM purposes, damages and inspection information (including cores, cracks, inspection windows, etc.) are well represented through the 'patch' strategy, that allows embedding all the necessary information in an easy to systematize/query manner, and indexed to the relevant date of inspection. Furthermore, scripts have been developed within Autodesk REVIT (Dynamo-Python) that allow that inspection data can be inputted or analysed directly in Microsoft

Excel, under a natural interface for people that have no expertise in BIM (e.g. an inspector). More details on these contexts can be found in [4].

Another important aspect to preserve is the visualization of inspection/damage data. Not only is the point cloud of each inspection preserved in the BIM model, but also photogrammetry-composed images of beam surfaces can be embedded into the model's surfaces (see Figure 7a), and spherical panoramas can be embedded into specific 'sphere' objects located at the exact spot where each 360 photo was taken in the inspections, as shown in Figure 7b. This has important benefits in the perception of evolution of damages by an experienced user that wants to navigate the model and observe the evolution of surface damages/aspect. Finally, the work reported herein has also tackled with success aspects related to semi-automatic inspection report generation (drawings) and exporting the model to BIM viewers (including through the use of the open IFC format) that allow the observation of the model and all its data to be made by stakeholders that might not hold licensing for BIM Software.

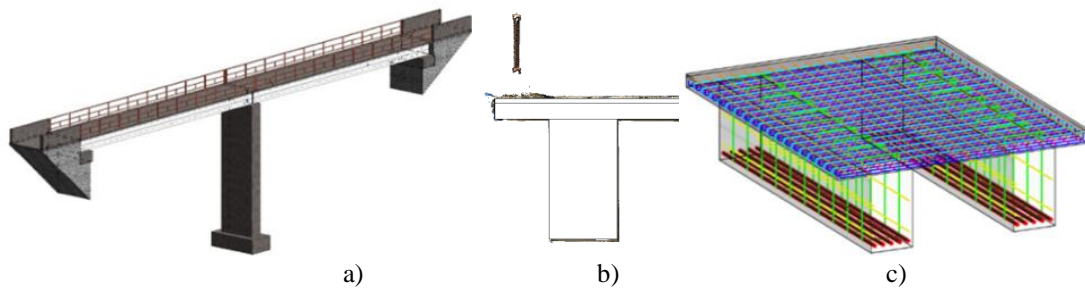


Figure 5: BIM Modelling: a) global overview of the model; b) comparison of BIM model and laser scanning at cross-sectional level; c) part of modelled reinforcement

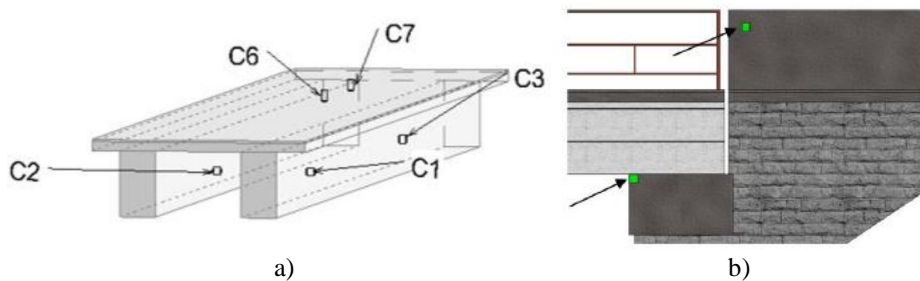


Figure 6: BIM Modelling: a) explicit modelling approach for cores; b) patch modelling approach for biological colonization

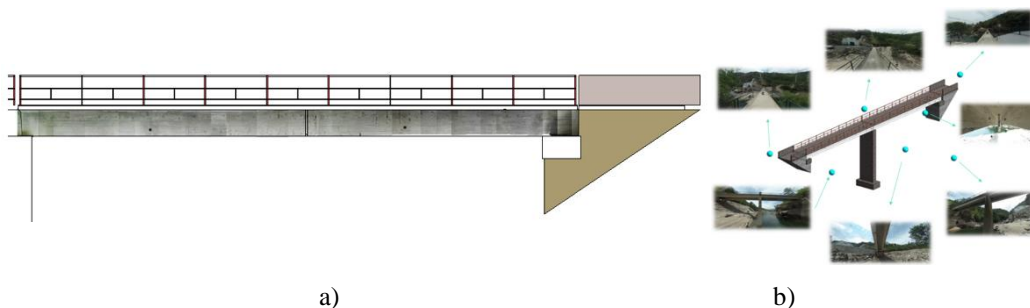


Figure 7: BIM Modelling: a) photogrammetry stitching on the surfaces of objects; b) sphere objects to host spherical panoramas

4. Conclusions

This paper addressed a proposed methodology to gather/register information pertaining operation and maintenance in reinforced concrete bridges, based on BIM modelling. The proposed methodology has been presented and discussed with support on the inspection of a Bridge located in the North of Portugal, for which no data was available before inspection. An extensive surveying inspection has been carried out including: classical measuring tape techniques; laser scanning; standard photography/photogrammetry; spherical panoramas; concrete core extraction; obtaining reinforcement samples; magnetic/GPR reinforcement detection; thermography; crack width measurement, among others. A BIM model has been established with specific action being taken in order to incorporate data that is not normally taken into account in design or 'facilities management' context, due to its specificity for structural inspection of reinforced concrete bridges. A proposal for simplified 'patch' representation of damage objects has been forwarded, and the layout of information in the model (including exporting to other stakeholders) has been address.

Based on the case study reported herein, it is considered that the proposed framework and corresponding workflow are feasible for implementation of bridge management systems.

Acknowledgements

This work was financially supported by: project POCI-01-0145-FEDER-007633 (ISISE), funded by FEDER funds through COMPETE2020 - Programa Operacional Competitividade e Internacionalização (POCI), and by national funds through FCT - Fundação para a Ciência e a Tecnologia. FCT and FEDER (COMPETE2020) are also acknowledged for the funding of the research project IntegraCrete PTDC/ECM-EST/1056/2014 (POCI-01-0145-FEDER-016841). The financial support of COST Action TU1404 through its several networking instruments is also gratefully acknowledged. The collaboration of Eng. Luís Santos from Leica GeoSystems Portugal is gratefully acknowledged, in view of his participation by carrying out the laser scanning survey of the bridge. The participation of the former MSc student of UMinho, João Rodrigues, in the inspection and early BIM modelling activities is also acknowledged.

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